63-3-2



TR-1102



# FLUID AMPLIFICATION

## Use of Epoxy Castings for Fluid Amplifier Design

David S. Marsh

Edward V. Hobbs

11 February 1963



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DA-5N03-01-003
OMS 5010.11.71200
HDL Proj. 31100

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David S. Marsh

Edward V. Hobbs

FOR THE COMMANDER:
Approved by

RD Hatcher

R. D. Hatcher
Chief, Laboratory 300

## CONTENTS

## ABSTRACT

An adjustable master unit has been used to make series of cast-epoxy fluid amplifiers that incorporate incremental dimensional changes. Subsequent unit testing identifies the best geometry for a given performance requirement. The process provides an inexpensive means of precisely producing the numerous units necessary for empirical design studies.

The basic rubber mold and epoxy casting process is described, as well as the adjustment of the master unit. Some other uses of epoxy castings in the fluid amplifier field are also described.


## 1. INTRODUCTION

In the design of fluid amplifiers, the most widely used approach at present is to take a current design that has some of the desired characteristics and to modify the geometry of the unit in increments. The design is tested after each change, and those changes that move unit performance in the desired direction are retained and followed up. Although this process can be greatly aided by water table studies, it is time consuming at best.

The ideal device for empirical design studies, perhaps, would be one in which all of the component parts are mounted on micrometer heads. With such a unit, the parts could then be precisely moved with the device in operation and the desired design could be "tuned-in." Such an approach was tried early in the program of fluid amplification development at Harry Diamond Laboratories, but sealing problems were never fully solved. Even when this unit was firmly clamped during tests, and unclamped to move the parts, leakage was still a problem.

One effective answer to the leakage problem is the one currently in use in metal units: the passages are formed in a solid piece of material, and the top surface is sealed to a cover plate.

A basic requirement for empirical design work as it has developed at HDL, then, is a series of configurations, each slightly different from the others which can be effectively sealed. Some idea of the number of different configurations to be tested in a program comes from a consideration of the number of parameters involved. In even a small program there may be as many as eight variables: length, setback, and angle of each of two walls, and downstream and transverse position of the splitter. In view of the number of units that may be necessary, a method of producing them in quantities of tens or dozens at low cost is required.

## 2. BACKGROUND

Methods of producing passages in a solid material that have been considered include conventional machining, etching in glass and plastic, injection molding, and epoxy casting.

In conventional machining, if a separate unit is made to incorporate each design change, valuable shop time is used in great amounts. In addition, successive units may vary slightly in those dimensions that should have remained unchanged. While not often serious, such changes add an unknown factor to the analysis of test data. To assure that only the desired dimensions are changed, sometimes only one unit is built. This unit is then tested, disassembled, modified, reassembled, and retested. This process takes less shop time than does the construction of separate units, but only a limited number of variations can be made on one unit. In addition, if the desired configuration is passed, it is usually not practical to "back up" and re-examine it. In any event, the number of combinations possible in such a study makes any process that involves machine work on each unit prohibitive in both time and money.

Both glass and plastic etching processes start with optical steps, so that design changes involve only changing an original drawing. Both, however, produce passages that narrow with depth. In the plastic-etch process, the bottoms of the passages are smooth, since they are actually the top surface of a metal base plate. Passages in the glass units, however, are somewhat rough on the bottom and sometimes show a slight "grain". Glass units must be handled with care and are not easily modified.

Injection molding has also been used, but it is more suited to large production runs after a design has been fixed.

## 3. EPOXY CASTING PROCESS

The epoxy casting process produces a one-piece unit quickly and at low cost. With a suitable master unit, the design can be changed quickly and easily.

### 3.1 Basic Process

The basic process of making plastic duplicates of an item, with the intermediate step of a rubber mold, is not new. The item to be duplicated is placed within a suitable form, which may be merely blocks of wood or metal arranged on a flat surface to contain the liquid rubber. The liquid, a silicone rubber compound that vulcanizes at room temperature, is then poured over and around the master. A vacuum at this time is helpful is removing bubbles of entrained air from the rubber. The rubber penetrates quite well into the surface details of the master. Vulcanizing time depends on heat and the curing agent used. It ranges from a few to 48 hr. When vulcanized, the mold is still sufficiently flexible and elastic to be removed from the master without great difficulty. The mold is examined after its removal from the master, and "flash" is trimmed off. Gross modifications may be carved into it at this time. When the mold is fully prepared, epoxy compound is poured in. Bubbles are removed from the epoxy either mechanically, with a pick or brush, or by means of a vacuum. After the epoxy has cured, the piece is removed from the mold. Here, again, the elasticity and flexibility of the rubber allow pieces to be removed which have no draft. With little or no further work, the resulting piece accurately duplicates the desired features of the original item.

### 3.2 Design Study of a Modified AND Unit

The casting process is now being applied in the design of a modified "and" unit for use in a binary adding machine. The unit has only one control jet. There is to be flow at one output when there is power and control jet pressure; with the control pressure removed but with the control passage still open, flow is to return to the opposite (control side) output.

The object of the design study is to determine the combination of wall angles, wall setbacks, and splitter position that will produce the desired flow behavior. A series of epoxy units is being made which incorporate incremental changes in the variables; testing of the units will show which configuration is best.

A special adjustable master has been made for this work (fig. 1 and 2). Since the design changes involve only the walls and splitter, these pieces are separate and movable. The power jet and most of the control jet were machined into a base plate. Most of the area usually occupied by the walls and splitter was routed out to the same depth as the power and control chambers, leaving a rim around the outer edge. The aspect ratio in the master is somewhat greater than that desired in the casting to allow for the removal of some material when the surface of the casting is smoothed. The nozzle width is 0.030 in. (Passages as narrow as 0.010 in. have been duplicated successfully.) The walls can be set back as required. With the wall parts shown, the wall angles are 0 deg on the left (control side), 16 deg on the right. The splitter angle is 5 deg.

When the movable parts of the master are in their desired locations, they are secured with C-clamps. Melted wax is then allowed to flow into the region between the wall pieces and the rim of the base plate. The wax flows under and between all of the movable parts, holding them in place and sealing any spaces between them against penetration by the rubber of the mold. The resulting wax fillets in the passages are scraped out before pouring the mold material.

After the casting is made, the top surface is smoothed by using wet sandpaper on a surface plate. Vacuum grease is used as a seal for the top plate. Since this program involves the testing of many units, the necessary fittings are installed in a cover plate that remains connected to the test setup. Units to be tested are then clamped to the top plate, so that a new unit may be easily and quickly connected to the rig. For more permanence, the cover can be secured in the usual manner with screws tapped into the epoxy or the cover, or the cover can be bonded in place to produce what amounts to a one-piece unit.

If the master is arranged for a new design in the morning, the mold can be ready the following day, releasing the master for another modification. The test piece can be available in the afternoon of the third day. In the normal investigation, new units can be made faster than they can be evaluated.

The splitter is not incorporated in the casting when its position is being evaluated. Instead, the number of castings is reduced somewhat by using a separate, movable splitter that can be clamped in place with the cover plate. When other parameters are being studied, however, the splitter is incorporated in the castings so that it will be in an identical position throughout a series of tests.

With such a system, a broad and rapid survey of an interesting range of dimensional changes is made. After this survey is made, it is possible to go back to an interesting part of the range for a more detailed evaluation of smaller increments.

## 4. OTHER ADVANTAGES EPOXY CASTING PROCESS

Once the optimum geometry is found, the process can be used to duplicate units indefinitely and with considerable uniformity and accuracy from copy to copy. If the mold becomes damaged, second and third generation molds can be made from the epoxy pieces with little or no loss of detail.

As a material for use in this work, epoxy has several desirable properties. It can be machined if necessary. It can be permanently bonded to other epoxy pieces, such as cover plates, or to itself if a unit should be broken. It can be made with different degrees of softness in each of several layers. Using this last feature, cover plates have been made which have a soft bottom surface that serves as a self-gasket and that have the connecting fittings molded in place (fig. 3).

In addition to the basic design study described above, this process has been used where machined modifications of a basic unit were required. For example, a study of different bleed passage configurations in a standard brass bistable unit was made as follows: Two epoxy units were made--one for a study of vortex bleeds, the other for a study of strongly diverging bleed passages (fig. 4). The machinability of epoxy is important in this work. Also of importance is the fact that the units are identical in all respects except for the bleed machining, since they began as duplicates of the same metal unit.

A three-stage counter originally etched in glass has also been duplicated in epoxy to obtain a unit in a material that could be machined. An additional benefit is that the casting is less fragile than the original. In the intermediate step, mold ridges, representing channels, were removed or changed to alter the channels in the epoxy (fig. 5).

## 5. CONCLUSION

The epoxy casting process is a valuable tool in the empirical design and small-scale production of fluid amplifier units. It provides exact, leak-free duplicates of a master unit. These castings can be machined, are rugged and low in cost, and can be made in a short time.


## ACKNOWLEDGEMENT

The castings described were made by John W. Tidler. His patience and skill were essential in making this design technique a success.

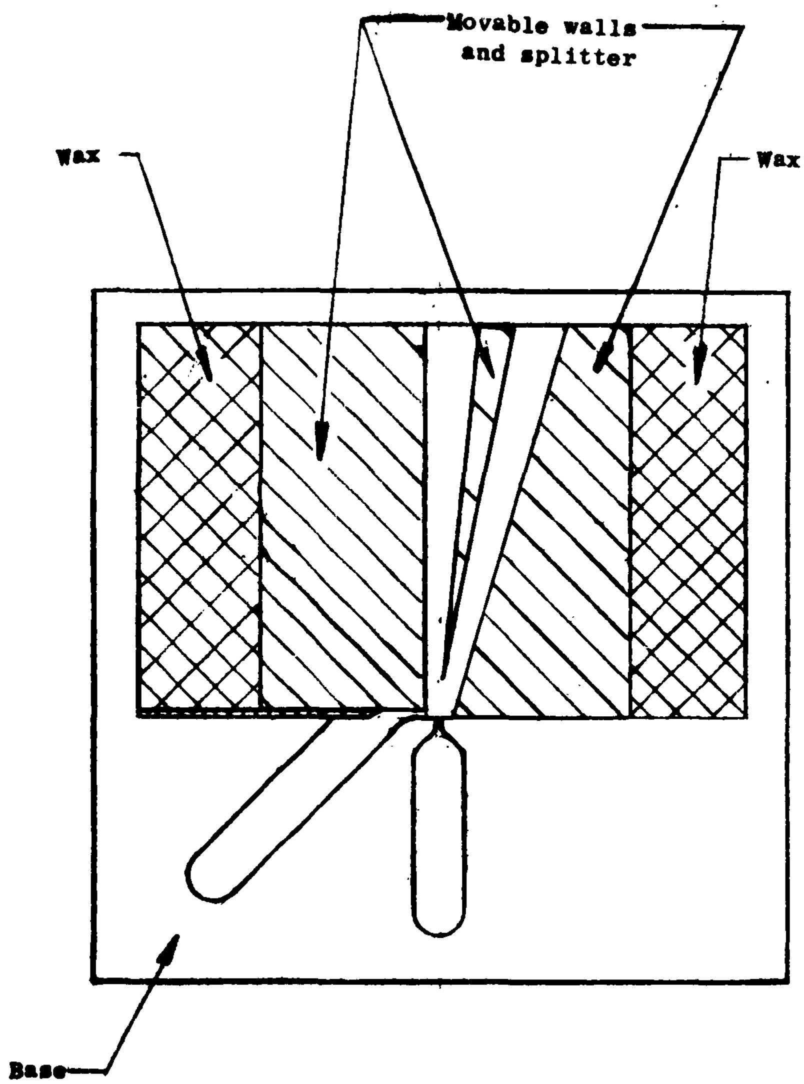
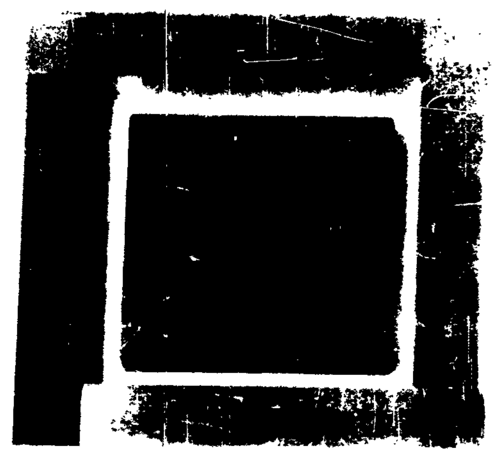
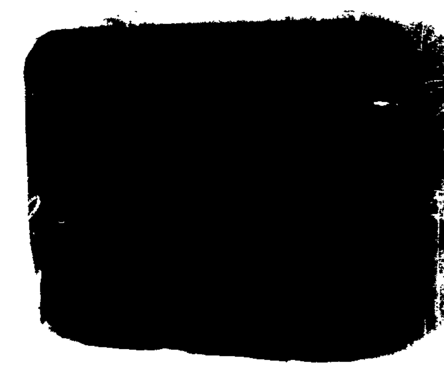



Figure 1. Adjustable master unit.

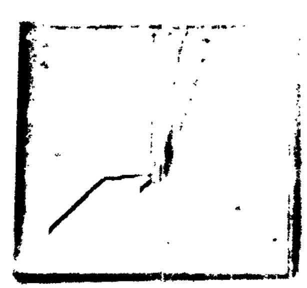
10



Adjustable master and form

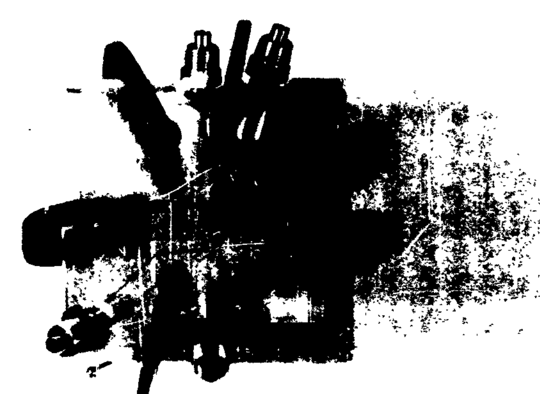


Mold



Rough casting

Finished casting



Unit clamped to cover

Figure 2. Steps in epoxy casting process using adjustable master.

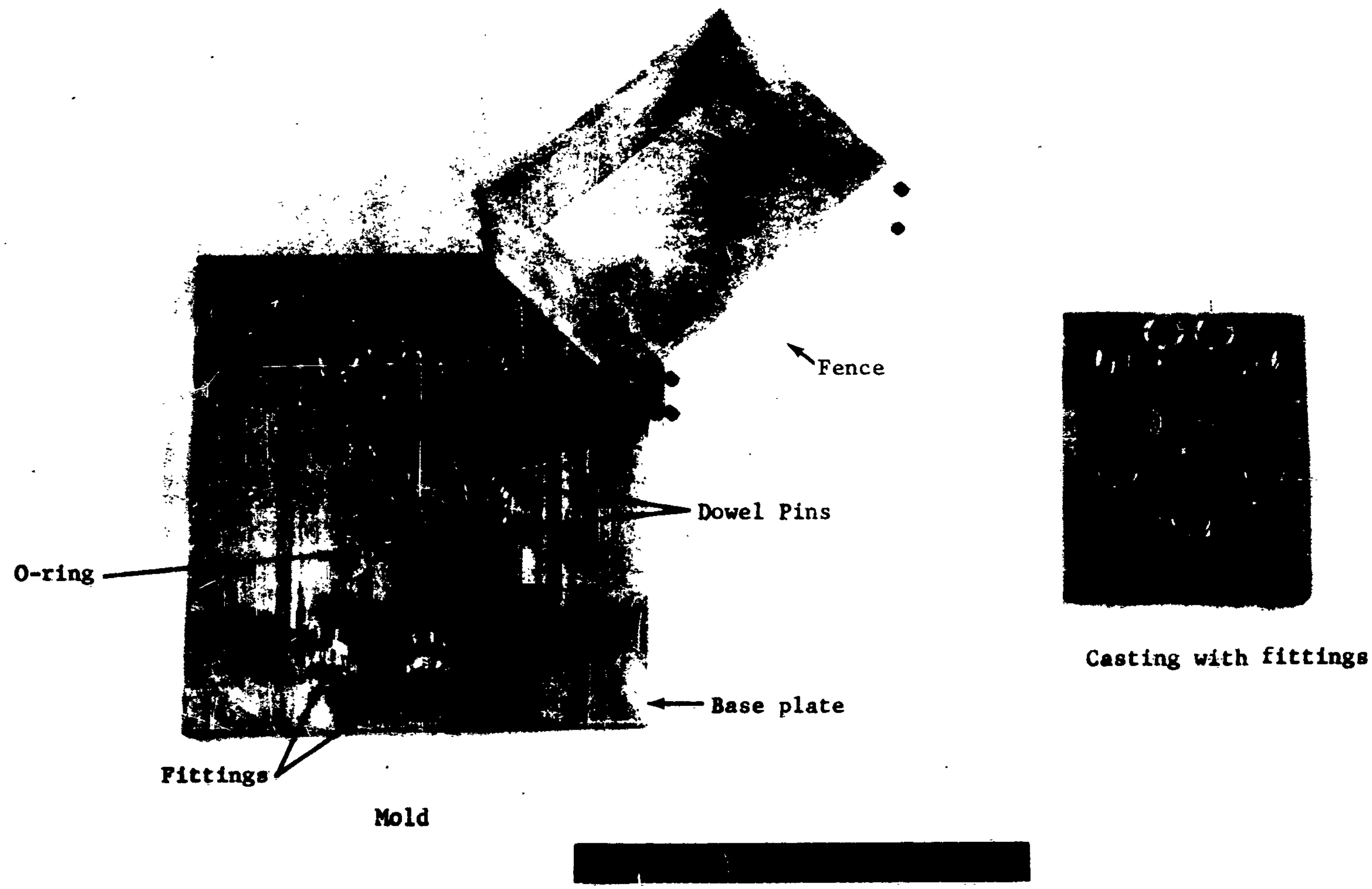
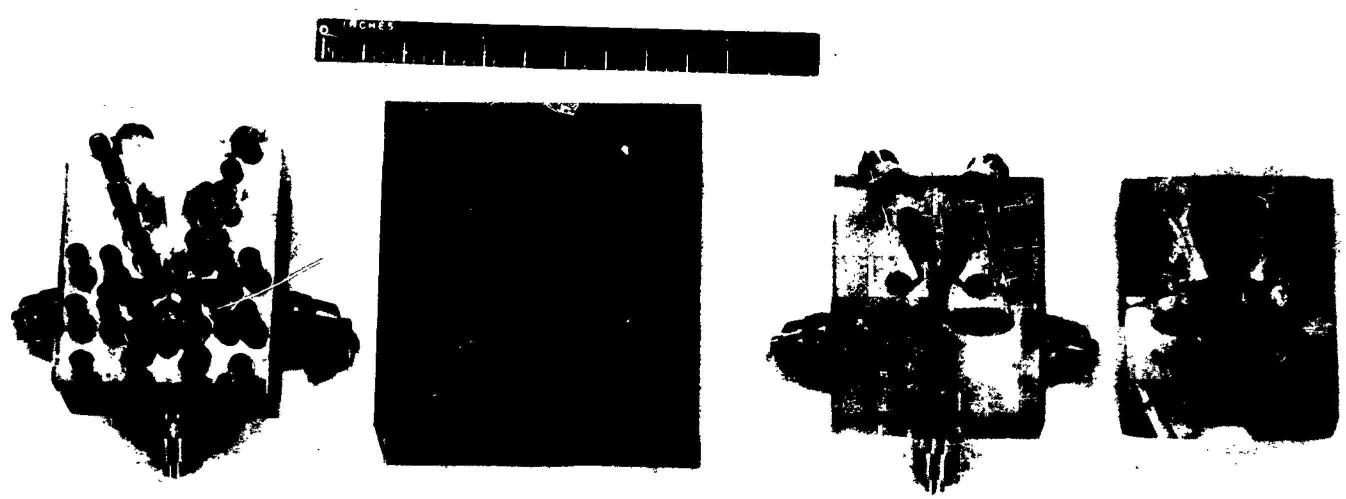



**Figure 3. Cover plate mold and casting.**




Original

Mold

Duplicates with machined bleeds

Figure 4. Bistable units with bleed passages.

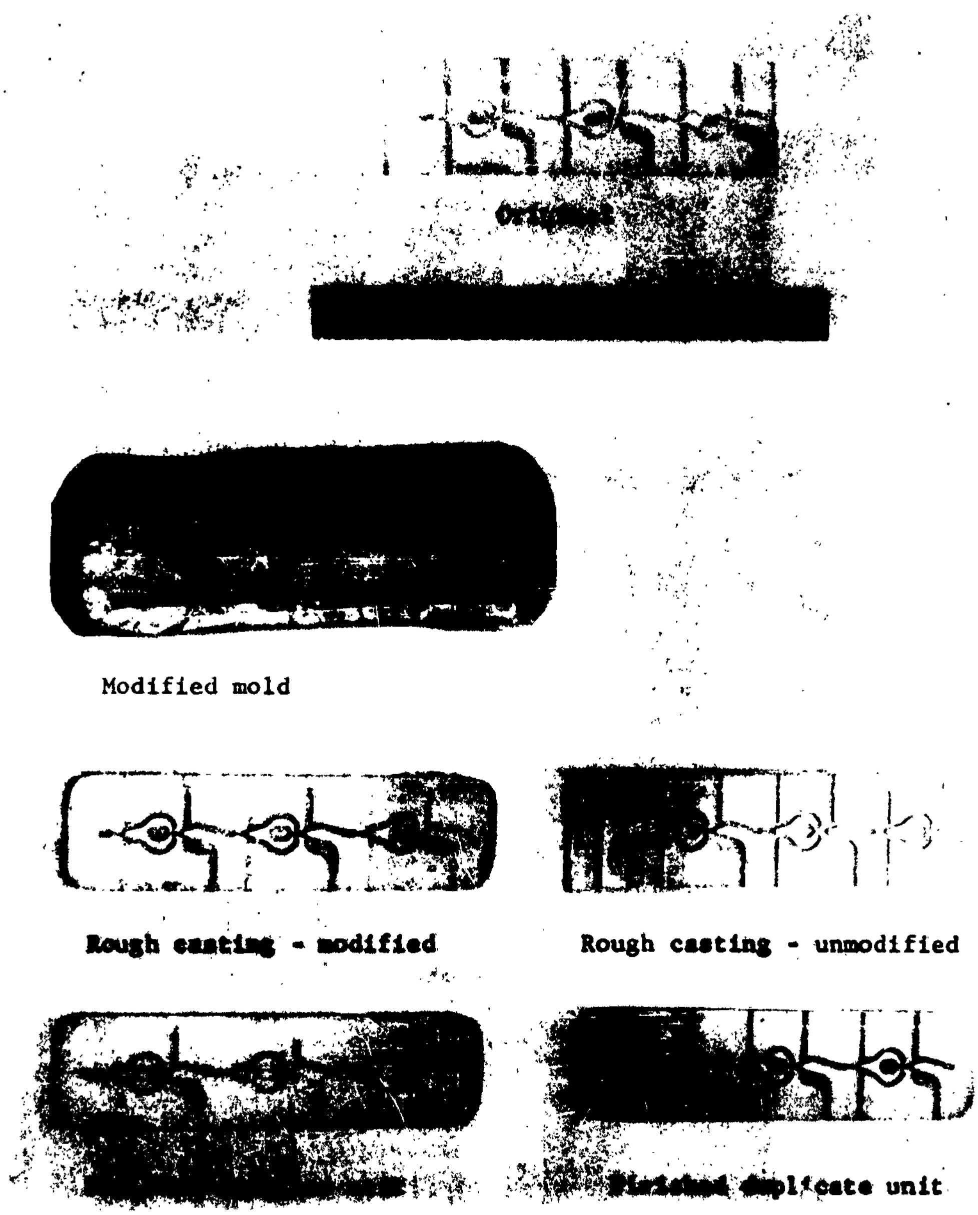



Figure 5. Three-stage counter.

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